EFFECT OF EXTERNAL MAGNETIC FIELD ON THE MECHANICAL PROPERTIES OF AMORPHOUS METALS

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By

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Dedicated to

Them that are naive enough
to attempt experimental work at
IIT/K.

CERTIFICATE

Certified that this work entitled, 'Effect of External Magnetic Field on the Mechanical Properties of Amorphous Metals', by Shri V. Ramakrishnan, has been carried out under my supervision and has not been submitted else where for the award of a degree.

(Amitabha Ghosh)
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November, 1979

PREFACE

The problems that beset experimental work are, very often, not peculiar to the nature of the work; more often than not such obstacles are inherent in the system in which one works. I would like to outline some of these 'general' stumbling blocks not to air grievances or 'let-off steam' but rather in the hope that they serve as pointers to the shape of the things to come to such of these naive enough to attempt such or similar ventures in the future.

A large part of the delay and the consequent agony, was the lack of information on the availability and location of sophisticated instrumentation. Here, I would suggest that the departmental library maintain a catalogue of what is available where.This would go a long way in reducing needless and time-consuming running around.

Much time and energy was spent in trying to do things manually; not that facilities are not available- it is just that these do not work and that too for trivial reasons. A reasonable effort on the part of the powers that be would make a nice place and wonderful haven to work in.

The most important lesson I learnt - and this was driven home repeatedly - never attempt any fabrication unless you have the fullest confidence in yourself. This is not to decry some of the wonderful help one gets; yet it remains inviolate.

But, if one likes challenges, these minor irritations not withstanding, believe me IT IS WORTH IT.

RAM

ACKNOWLEDGEMENTS

Amitabha Ghosh - this name shall always bring pleasant memories of an inspiring teacher, a patient advisor and a wonderful person to my mind. His continued involvement in my work, his sharing of my ups and my downs, my joys AND my frustrations have lent his personal touch to my work; for this I shall be ever-grateful to him.

My gratitude to Dr. A.K. Majumdar for his munificence in providing me with a more than reasonable length of a scarce material, for making all his private technical papers available to me and for the readiness with which he gave off his time.

I acknowledge with pleasure, the willingness with which Dr. N.G.R. Iyengar, made available the creep testing facility. To Dr. M.K. Muju, Dr. G.S. Murthy, and Dr. T.R. Ramachandran, go my thanks for the many useful tips they gave me.

If Dr. Ghosh was my guide and friend, Mr. R.M. Jha [Teek Hi, Ho Jayaga], STA, Mech. Engg. I found another friend and a personal philosopher. But for his skilled hands and nimble wit much of what I conceived would never have been delivered.

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This acknowledgement would be incomplete without a line [I could write a monograph] for those magnificent companions who evinced as keen an interest in my work as in my 'Phuttaas'. To 'Dada' Karnick, 'Dumbu' Prabhakar, 'Pudingi' Vittal, Somenathdha, 'Behari' Arvind Tiwari, 'Jaded Bean' Surd, 'Kitchukutty' Krishnan, go my warm-hearted appreciation and gratitude. Boys you made it worth while.

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ABSTRACT

This work is an enquiry into some characteristics and behaviour of ferro-magnetic amorphous glasses in a steady, external magnetic field. The purpose of the work is two fold:(a) To verify, experimentally, whether moving dislocations play a leading role in the flow mechanisms of these amorphous materials, as is the case in crystalline materials; (b) to check the applicability and correctness of the theory proposed by Ghosh and Muju for the mechanical wear characteristics of crystalline materials in an externally applied steady magnetic field, when applied to amorphous materials. The vehicle chosen for the experimental testing of such mechanical properties as stress-relaxation, creep and wear in both magnetic and non-magnetic environments is an alloy of Fe-Ni-Mo-B, quenched at such rates (10^6 °C/sec.) as to yield an amorphous structure. Experiments indicate that (a) defects do appear to be the cause of flow; but this defect movement is distinctly different in many aspects from that in crystalline materials and (b) the Ghosh-Muju theory is valid; though the enhancement of certain behaviours due to magnetic field, in this case, is not as significant as in crystalline materials.

CHAPTER I

INTRODUCTION TO METALLIC GLASSES

1.0 Introduction

Engineering materials, and for the matter, most materials known to man, can be structurally classified as being either (a) crystalline or (b) amorphous. Almost all metals, in the solid state, bear crystalline characteristics; many important characteristics that typify a material have been explained on the basis of their crystalline structure.

Unlike crystalline substances, where a single geometric three dimensional structure is arranged periodically in space, amorphous materials have not been amenable to such an easy and simplistic concept. Many of their properties await investigation. Of a sudden they have assumed a rather disproportionate level of importance because of the development of new class of materials called 'metallic glasses' - more so because the major constituent is a metal, which till recently was thought of as having only a crystalline state, is in the AMORPHOUS STATE. How and why they achieve this state is the subject matter of the ensuing paragraphs of this chapter.

1.1 Metallic Glass

The amorphous material used in the study is a Fe-Ni glassy alloy in the form of tapes with dimensions 12.5 x 0.1 mm^2.

This alloy, referred to commonly as Metglas^R has as its constituents one or more transition metals and a metalloid. The transition metals in this particular alloy are ferrous (40 %) and nickel (38 %); the metalloid being boron (18 %) 4% of molybdenum completes the composition.

1.1.1 Splat-Cooled Metals

A metallic glass, such as the one used, may be considered to be an undercooled liquid in which the geometrical arrangement of the liquid state has been retained at temperatures where the viscous relaxation time is long compared to 1 sec. This long relaxation time makes them mechanically rigid [1]. The retention of the liquid structure is due to the extremely high quenching rates used (of the order of $10^5 - 10^6$ °C/Sec.). The interesting question now is - How are such cooling rates achieved? In its most elementary form they are achieved as detailed below.

A droplet of the molten alloy is projected at a high velocity (150 - 300 m/sec.) on to a cooled substrate. This

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R - Metglas^R is the registered trade-mark of Allied Chemical Corporation, New Jersey, USA.

substrate constitutes the anvil. An instant before the droplet strikes the anvil, a complex triggering mechanism activates a fast moving piston. Trapped between the ~~pi~~ piston and anvil, both of which are coated with beryllium copper, the droplet gets splattered over the surface of the anvil. The cooling is effected by conduction. Since the molten metal is splattered onto a substrate, the end products are referred to as 'Splat-cooled' metals and the process is called 'Splat-cooling'. Alternatively the process is also referred to as liquid-quenching, liquisol-quenching.

1.1.2 The Manufacturing Process:

The earliest technique developed is due to Duwez and Willens [2]. In brief the process is: A shock wave, propogated through an inert gas at high pressure, ruptures a thin mylar diaphragm separating the high from the low pressure chamber. The shock wave carries with it a small quantity (100 mg) of the melt contained in a graphite crucible; the droplet impinges, with considerable velocity on a copper substrate. The droplet spreads out over the substrate as a thin foil. The drawback is that thin irregular ribbons obtain as the product.

The piston and anvil technique, already outlined in Section 1.1.1 is due to Pietrokowsky. A variety of innovations have been added to improve the process.

The other processes used, detailed exhaustively by Anantharaman et al [3], are:

(1) The Centrifuge

(2) The Torsion catapult

(3) The Plasma - Jet Spray Technique

(4) The Filamentry Casting Technique

The thickness of these materials varies between 15 μ to 0.2 mm, depending on the process used. The length varies from a few mm to thousands of metres. In fact, modern techniques produce 1800 - 2000 metres of the material per minute.

1.1.3 Properties and Uses

Splat-cooling has gained so much popularity in so short a time because the end-product offers an intriguing combination of properties, many of which await investigation [3].

Metallic glasses are elastically stiff; strengths above 25000 Kg/cm^2 are not uncommon; some of them can be plastically sheared to strains greater than unity; yet others have high corrosion resistance; still others have low electrical and thermal conductivities; some have high magnetic permeabilities and low coercive forces; they propogate sound waves with low attenuation. Despite being

as hard as fully martensitic steels, unexpectedly they are soft ferromagnets. This fascinating combination of properties, coupled with their manufacture being economic in terms of energy, capital and time has, as J.J. Gilman puts it '...given birth to a new branch of metallurgical technology'.

Since, these materials can be heat treated and cold rolled, they have a wide variety of uses, though not many of them mechanical. Some of the uses to which these materials are put to are:

(1) In power transformers to replace silicon-iron because of better saturation induction.

(2) In Resistance-Thermometers which can measure 1.5° - 300° K; the special feature is that its sensitivity increases with decreasing temperature.

(3) As Amorphous Ferromagnets.

(4) As Magnetic Shields.

(5) As Sacrificial Anodes.

Unfortunately, many of the properties are lost on crystallisation which usually occurs at temperatures roughly equal to one half of the melting temperature.

A brief summary of the flow mechanisms is outlined in Section 2.3.

1.2 Review of Previous Work

A comprehensive review of work done in the area is listed in [29] and the various stages of the progress have been reviewed in [3 and 21]. The early work of Duwez, Willens, Pietrokowsky, Polk, Davies and their coworkers have been devoted primarily to the development of the manufacturing process, the evolution of which is traced beautifully by Anantharaman et al. [3]. Much of the initial experimentation was limited to the determination of the mechanical, thermal [30 to 33] and other properties [25 to 27] for wide range of materials that the term 'metglas' encompasses. This was the data collection stage on the so called 'Duwez's stupid alloys'; while the early workers attempted to establish a structural picture for explaining the physical properties like density, RDF distribution, magnetostriction etc. it was not until the realization came that some of these glasses can be cold rolled and plastically deformed that a rigorous modelling was attempted [20,21,22,34]. Present work is directed towards getting information which could be useful in building a rigorous structural model and in enhancing the mechanical aspects of the material.

1.3 Objective and Scope of the Work

While much work has been done in investigating the mechanical properties of these glasses, almost no work seems to have been done to evaluate the effect of a steady external magnetic field on the mechanical behaviour of metallic glasses.

It is well known [7 to 11] that an external magnetic field, affects drastically the mechanical properties like creep, yield stress, wear etc. of crystalline materials. If, as Gilman [1] suggests, that moving dislocations constitute the basic flow mechanism in glasses, all the above mentioned properties should be enhanced in an external magnetic field in the case of amorphous materials. If it is not the predominant mode, the Ghosh-Muju theory suggests that this magnetic field should have little or no effect on these properties.

The purpose of this work is to verify, experimentally, the effect of the external magnetic field on

(a) Stress-relaxation,
(b) Creep, and
(c) Wear.

The experimental details are outlined in the Chapter III.

CHAPTER II

INELASTIC DEFORMATION AND INFLUENCE OF MAGNETIC FIELD

2.1 Preamble

Real crystals contain defects. These cause the geometry of the real crystal to be altered as compared with that of an ideal one. Such defects, normally called dislocations, are inherently present in all real crystals and are generated during crystal growth and any subsequent deformation.

The fact that in real crystals plastic deformation, sets in at stresses of 10^{-3} to 10^{-4} G, when compared to the theoretical strength of G/30 [4] and a lot of other experimental evidence [5] brings out the close relation between dislocation mobility and plastic deformation. Carrington et al. [6] have provided evidence to support the belief that these dislocations are distributed in nicely formed networks throughout the material and that some of the dislocation lines of the network are free to move. Such movements are evinced as material deformations.

There are a variety of such dislocations and these can move in a host of ways [7,8]. It is the movement of such dislocations that has attracted the attention of many workers.

2.1.1 The Effect of an External Magnetic Field on Crystalline Materials

Crystals of ferromagnetic materials are normally divided into magnetic (Weiss) domains. In each domain the resultant magnetic intensity lies along one set of equivalent easy directions of magnetization. The Block walls forming the boundaries between the domains have a finite width and energy. Normally, across a Block wall there is a reversal of the direction of the resultant magnetization; under the influence of an external field the magnetization in each domain rotates into the easy direction closest to the applied field.

Magnetostriction is a strain produced by magnetization in a domain and results in a coupling between the magnetization and internal stress fields; when a field is applied externally, the local directions of magnetizations alter in a fashion designed to lower the internal stress.

The effect of this reduction in internal stress on creep and wear has been studied intensively [9 to 11]. Since the internal stress reduces, creep increases phenomenally as does wear of the ferromagnetic material when rubbed against the surface of a material with lower magnetic permiability.

2.2 Structure of Amorphous Materials

2.2.1 Introduction

The structures of amorphous materials is based on a model proposed by Prof. J.D. Bernal [12,13] as early as 1959. This model referred to as the Bernal hard sphere model or the Dense Random Packing (DRP) model is outlined in brief. Also is given a sketch of the Polk model [14,15] which is essentially a modification of the Bernal model.

2.2.2 The Structural Models

(a) The Bernal Model

The essential feature of this theory is that it treats liquids, for which it was constructed, as a homogeneous, coherent and essentially irregular assemblages of molecules containing no crystalline regions or holes large enough to admit another molecule. The central geometrical thesis arrived at on the basis of an emperical method is that irregular dense packing and pentagonal arrangements are necessarily connected; no proof, however, is provided.

On the basis of a physical model and using some elegant simulation techniques, Bernal postulated that, 'in an ideal liquid structure, the molecular centres lie at the apices of a set of empty polyhedra (holes) with equal edges or a combination of them. These polyhedra are platonic

regular (1) tetrahedra; (2) octahedra; archimedean (3) triagonal prisms; (4) archimedean antiprisms; and (5) tetragonal dodecahedra. The presence of the three latter forms prevents any long range order...'. Bernal further stated that any amorphous structure is a random densely packed mixture of the above five types of polyhedra sharing faces. Polk [15] has, on the basis of theoretical and experimental work proved that the latter three types predominate; within these three the predominance is governed by demands of conservation of atomic volume, mechanical stability and a host of other stringent requirements [12]. Two prominent features which stand out starkly in the Bernal model are (1) the existence of holes (2) the fact that no atom can fill these holes.

(b) The Polk Model

While Polk assumed the existence of the hard spheres (atoms) at the vertices of polyhedral holes, he postulated, that in a metal-metalloid system such as metallic glasses, the metal atoms occupy the vertices while the metalloid atoms occupy the holes. Polk has further shown that the latter three types of holes as stated by Bernal predominate. He has, however, reported on the basis of experimental data that not all of these holes get filled. This is so because,

(1) Conservation of atomic volume precludes a 100% occupancy,

(2) There is certain to be a range of hole sizes for each type of hole and it may be that only a certain fraction are suitable as metalloid locations.

At higher temperatures, the metallic atom arrangement would be more loose and hence a larger number of the holes get filled by the metalloid atoms. Further, because of the larger cores of the transition metals (Fe, Co, Ni), the atoms, as predicted by Bernal tend to 'jam', giving a continuous solid, amorphous structure. The entire structural modelling appears to be consistent with the free-volume theory proposed by Chen and Turnbull [16,17] and Cohen and Turnbull [18,19].

2.3 The Flow Mechanism in Metallic Glasses:

Many workers [20 to 22] on the basis of inspection of samples, fracture surfaces and metallography, after testing, have shown that two basic modes of deformation exist: homogeneous flow, where each volume element of the material contributes to the strain and inhomogeneous flow, where the strain is localized in very thin bands. The former mechanism is operative at low stresses and high temperatures. Here, in uniaxial tension the material thins down uniformly during deformation. Inhomogeneous flow occurs at high stress levels, the flow, being strain rate insensitive, is ideally plastic and is localized in very

thin shear bands. Slip on these planes is very extensive; to the extent that it weakens the material and fracture occurs along the shear bands. The basic physical process underlying this phenomenon is local 'softening' of the material. There is much evidence [21] to show that strain-hardening is almost absent. In fact, experiments indicate that plastic flow is reversible - a phenomenon unknown in crystalline materials.

Now, localization of flow in shear bands, requires that there is some structural change of the material inside the bands. Two mechanisms have been suggested.

(1) The microscopic mechanism which governs homogeneous and inhomogeneous flow is based on the assumption that flow occurs as a result of number of individual jumps, the constraint being that the atom must have a hole in the neighbourhood, large enough to accommodate its atomic volume v^+. It is further assumed that both the initial and final positions of this atom are positions of relative stability. The activation energy for the jump is either provided by the thermal fluctuations or by some external force. When an external force like a shear stress, is applied, the atomic jumps are biased in the direction of the force [Jumps, are possible in both directions]. This results in a net forward flux of atoms and forms the basic mechanism of flow.

This has led some investigators to suggest that flow is largely due to 'generalised dislocations' somewhat akin to that in crystalline materials.

Pampillo, Spaepen, Polk and many others have contested this and suggest formation of slip bands and postulate that the resultant plastic flow is due to the 'dilatancy' effect. Argon [22], among others has discussed this in detail. He identifies, 'free volume' and 'free energies' as bases to his hypothesis.

Free volume refers to the fraction of matter having a lower atomic co-ordination than that in a reference material having a dense random packing. Since these volumes have a lower co-ordination they require less energy, the free energy, to cause them to jump i.e. free volume and free energy are inversely related. Under an applied stress, a few isolated free volumes with the smallest free energies can be caused to 'jump'. Under substantially higher stresses a larger fraction of flow units, with higher energies than the ones initially activated, enter the picture until at a certain well defined stress level the shearable flow units give contiguously sheared regions throughout the volume. Since the initial structure is a random packing of hard spheres the sheared structure inside these regions should also be randomly packed and statistically similar to the initial structure. Thus, the original structure is

repeatedly regenerated. This is where the second mechanism, outlined below differs. But this does not explain the softening mechanisms. Polk and Turnbull have suggested that the mechanism for softening is as under.

They suggest that the change in the structural characteristics is a nett result of two competing processes.

a) The shear induced disordering,(as outlined above)is offset by

b) a diffusion controlled reordering.

More basically, when an atom jumps into a new site, it may cause atoms in the vicinity to alter their positions or squeeze them (volumetric decrease). Because of the large free volumes associated with such sites, relaxation restores equilibrium, relaxation being effected by minor atomic reordering. It is now clear that dilation occurs. Argon has explained that such dilatation, once it exceeds a certain threshold value can give rise to the localization of slip bands.

Now, to consider the model suggested by Polk and Pampillo [23].

(2) Maddin and Masumoto [24] have reported the onset of crystallization of metallic glasses under an external load. Polk and Turnbull have theorised that once crystallisation sets in, agglomeration of crystals results. Once it reaches

a certain critical value the flow slows down. This is how they have explained transient and steady state creep in glasses. These agglomerated sections are capable of diffusing in a manner similar to the annihilation of dislocation at grain boundaries in crystalline materials.

This disordering - reordering may be the reason for the creep progressing in discrete jumps as is reported by Gilman [1] and indeed as was found in the course of the experimental work.

Various modes of fracture, all leaning on this hypothesis have been proposed [20].

2.4 The Magnetic Nature of Metallic Glasses

The past few years have seen a large number of ferromagnetic metallic glasses come into being. O'Handley, Chow Ray and others [25 to 27] have reported extensively on the magnetic behaviour of these materials. Of interest, here is the existence of magnetic domains in amorphous metals. Not only are there domains, but these domains are extremely large compared to those in normal crystalline materials. In Fe-Ni base alloys, the domain size ranges between 400 and 600 microns. These domains are usually inclined to the axis of the ribbon and is due to the anisotropy in the material. As in crystalline materials, the domain thickness changes in discrete steps. In crystalline materials

the cooperative contributions from many grains yields a continuous characteristic curve in bulk measurements [28]. This continuous characteristic is not apparent in amorphous materials. This is in good agreement with flow mechanisms outlined in Section 2.3.

CHAPTER III

EXPERIMENTAL DETAILS

3.1 Synopsis

The following mechanical tests were conducted on the material. All the tests were duplicated in a magnetic field varying between 60 and 120 gauss in strength:

(a) Stress-Relaxation

(b) Creep

(c) Wear against

  (i) mild steel (ferromagnetic)

  (ii) brass (non-ferromagnetic)

3.2 The Stress-Relaxation Test

This test was conducted on the INSTRON (Model No. TCTML). The test specimen was held between grips modified marginally to suit the ribbon. Uncompressed, coarse leather, with squares embossed on it, was inserted between the jaws - one piece against each of two jaws. The ribbon was held between the leather faces, the jaws closed and the load applied (Fig. 1). The material was loaded to a maximum of 50 Kgs. Once the load reached the pre-set value, the motion of the upper head of the machine was stopped. Sufficient time was allowed to elapse, to ensure a reasonable,

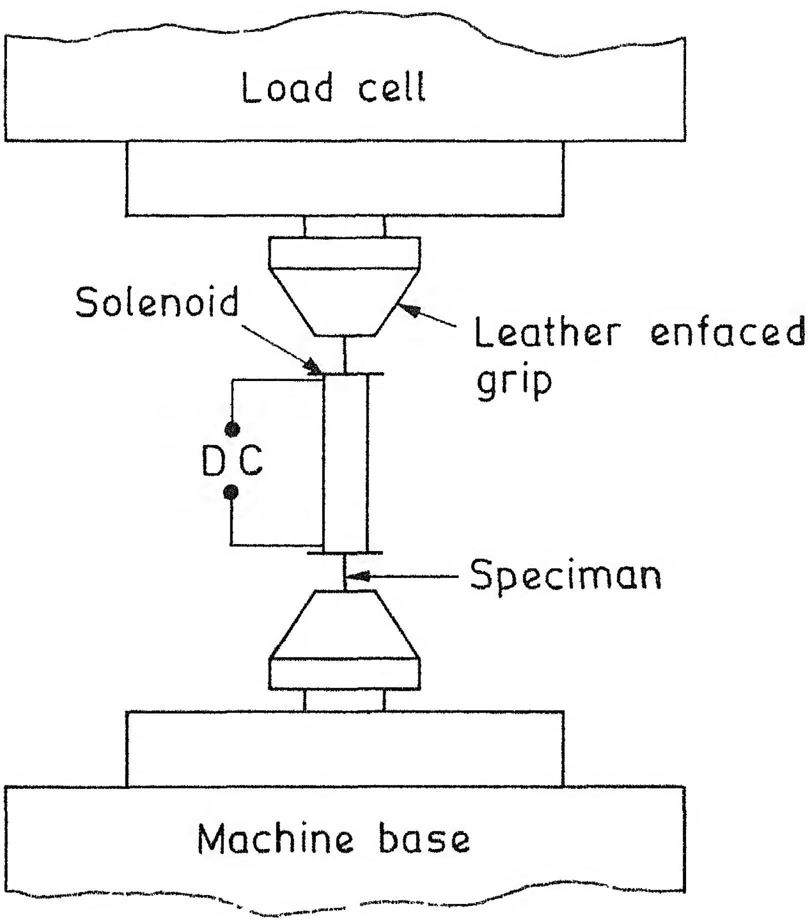


Fig. 1 Schematic view of relaxation test.

measurable drop in load - the drop in load being the stress relaxation.

The experiment was repeated after introducing a solenoid, through the hollow core of which passed the ribbon, between the jaws. The solenoid was excited through a steady external D.C. Source. The loading and unloading pattern was identical to the non-magnetic test. The test was repeated twice.

3.3 The Creep - Test

The creep - test was done in two stages.

The first stage was a room - temperature test; it was performed on a locally fabricated set up with dial gauges positioned strategically, to measure extension and slip if any. Since the results were not very encouraging, the experiment was not duplicated in a magnetic medium.

In the second phase the material was tested for creep, on a RIEHILE, beam and lever type Creep Testing Machine, under a steady load of 30 Kgs. at 175°C.

The material was gripped between specially made leather enfaced grips suited to the machine (Plate 2). An electric furnace enclosed a goodly length of the specimen. Two solenoids in series were used one on either side of the furnace. A Daytronic LVDT and amplifier system actuated

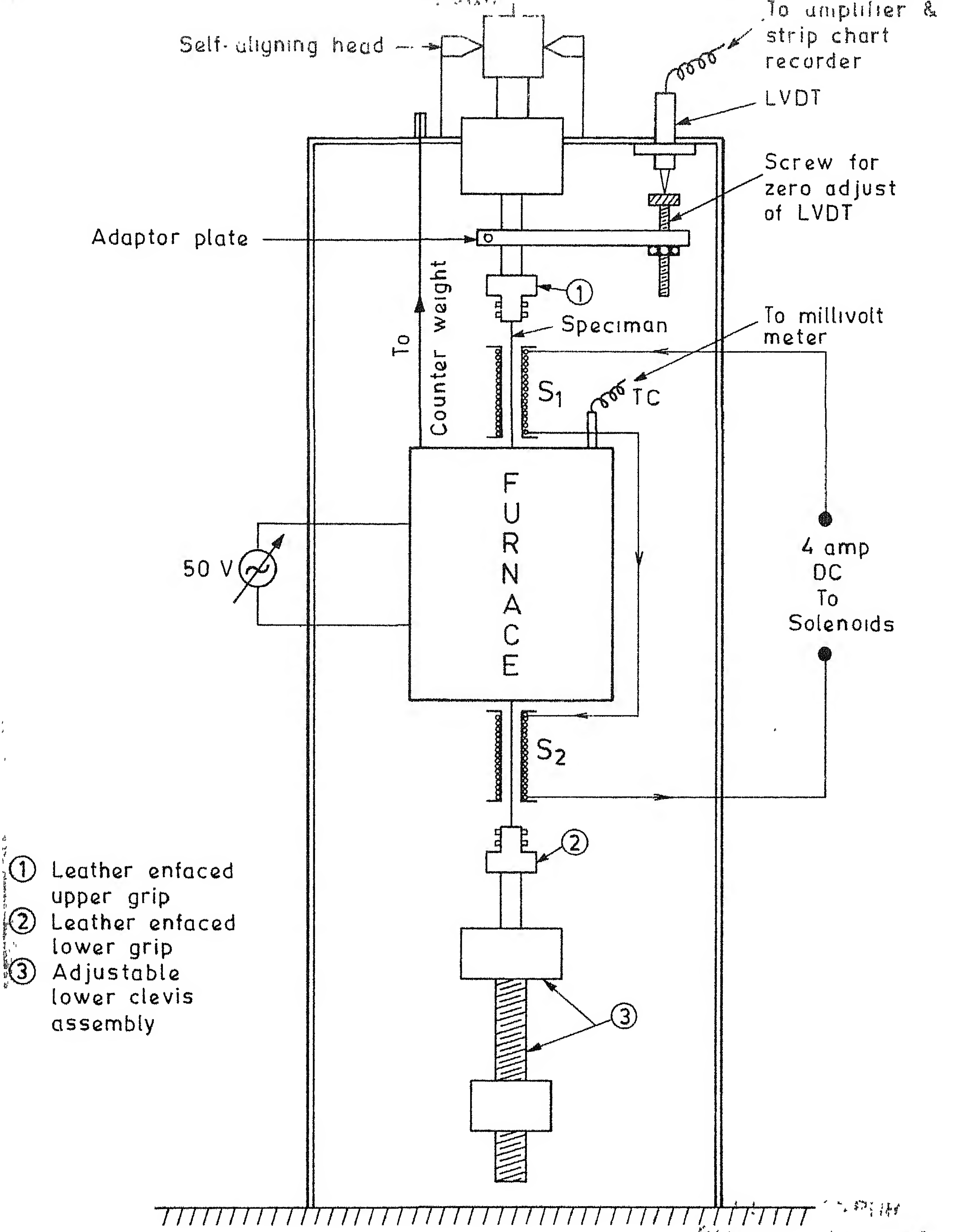


Fig. 2 Schematic view of creep - test machine.

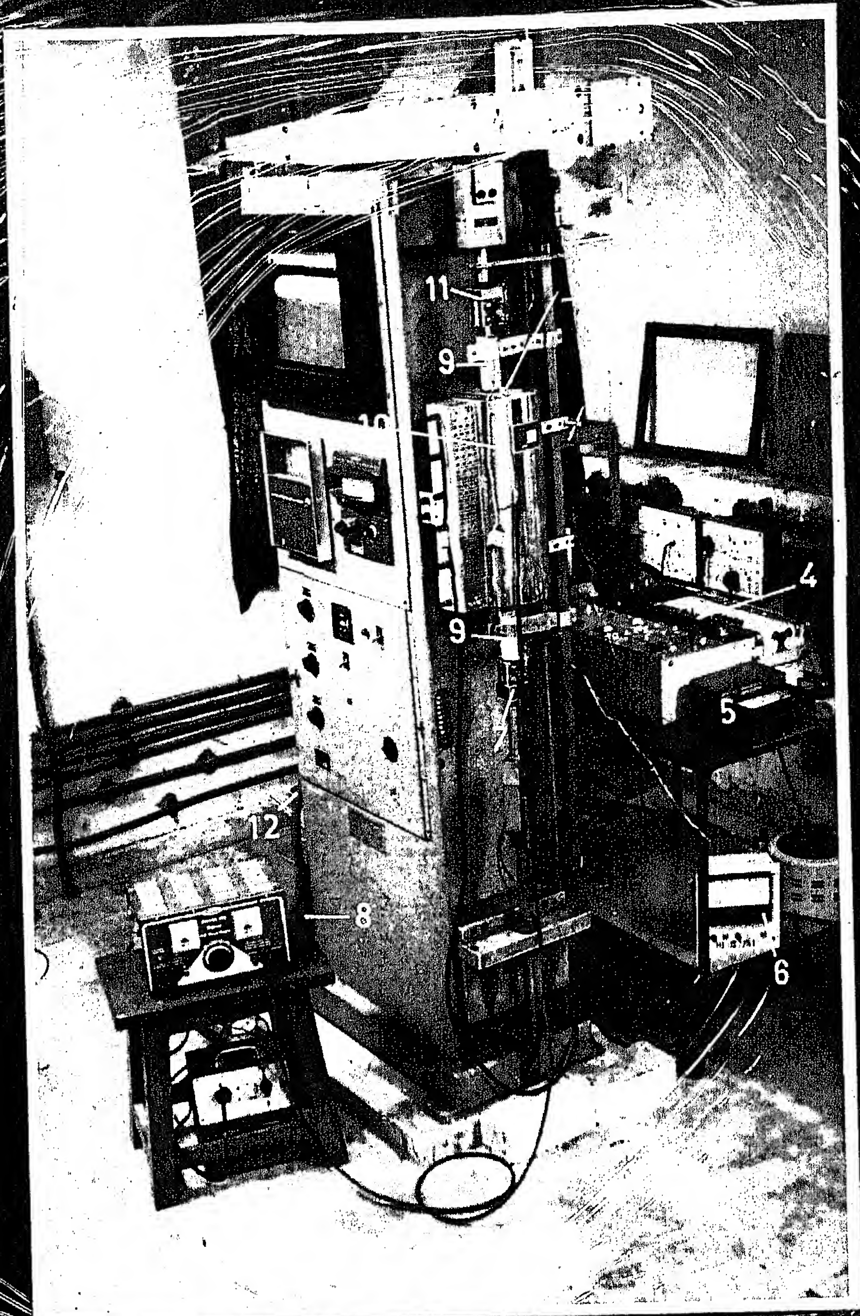


PLATE 1

1 LVDT	7 Lower grip
2 Adjust screw	8 D.C. source
3 Thermocouple	9 Solenoids .
4 Recorder	10 Furnace
5 Millivoltmeter	11 Upper grip
6 Amplifier	12 Weights

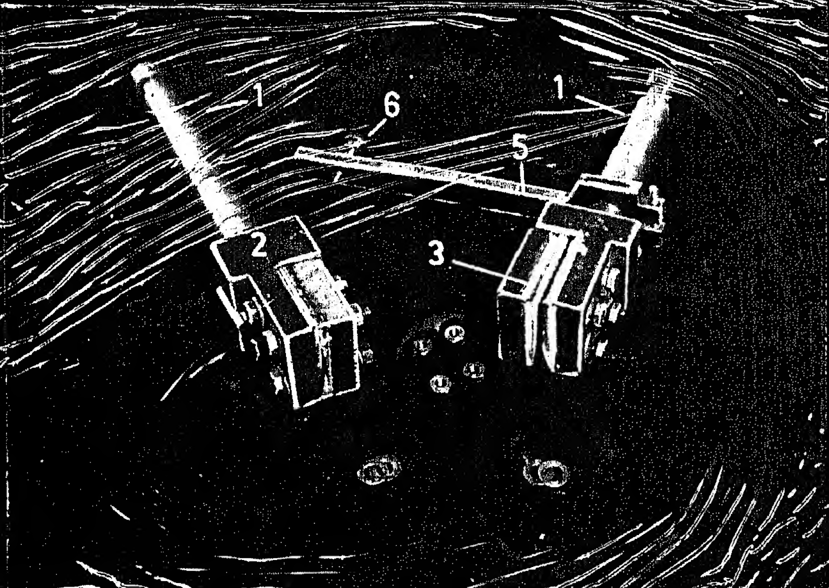


PLATE 2

1 Grip adaptors 4 Upper grip
2 Lower grip 5 Screw adaptor
3 Leather insert 6 Adjust screw

an Encardiorite recorder. An adaptor plate, carrying a fine-pitch knurled screw and lock nut at one end and fixed to the upper grip rod, was used to actuate the plunger of the LVDT. The temperature was monitored using a chromel-alumel thermocouple and millivoltmeter. In both magnetic and non-magnetic experiments, the Aluminium core solenoids were retained in place to ensure identical heat-transfer characteristics. However, only in the former case were they energised to strengths of 125 gauss (Fig. 2, Plate 1).

The procedure involved in starting a run was rather delicate and hence is outlined.

The upper grip, with the material firmly anchored in it, was locked in position on the machine. The material was threaded through the solenoids and the furnace (at operating temperature). The system was left idle for an hour to ensure that the linear expansion of the metglas had no deletirious effect on the creep data. Thereafter, the lower end of the ribbon was clamped between the leather strips in the lower grip and the weight pan loaded. Only after the initial extension reached a steady-state was the adjustable screw brought to bear on the LVDT plunger, (the initial extension was well beyond the range of the LVDT) and the recording system started. The time for which the record was maintained varied between 6 - 14 hours; the

limitation was the minimum speed on the Encardiorite - 1 mm/sec.

In all ten runs were made. But data presented is only for 3 cases as in earlier trials the measuring and recording systems were unknown quantities.

3.4 <u>The Wear Test</u>:

A HMT LB 25, centre lathe was used to test the wear characteristics of the metglass. As already mentioned in Sec. 3.1, the rubbing was effected against mild steel and brass. In both cases the following variations were used.

(1) A non-magnetic Pin

(2) A pin magnetised to strengths of

(i) 60 gauss

(ii) 125 gauss

Again, these conditions were used in two classes of trials

(1) Length of rub = 30 mm

(2) Time of rub = 1 min.

In all cases, the spindle speeds utilized were: 100, 160, 250, 500 (rpm). (The lower and higher speeds induced an uncomfortable degree of vibration: the speed intermediate between 250 and 500 was non functional). The feed was 0.1 mm/rev. in all trials; a load of 5 Kgs. was used consistently. The pins were magnetised in situ. 18 Gauge wire wound around a perspex core, whose internal dimensions were

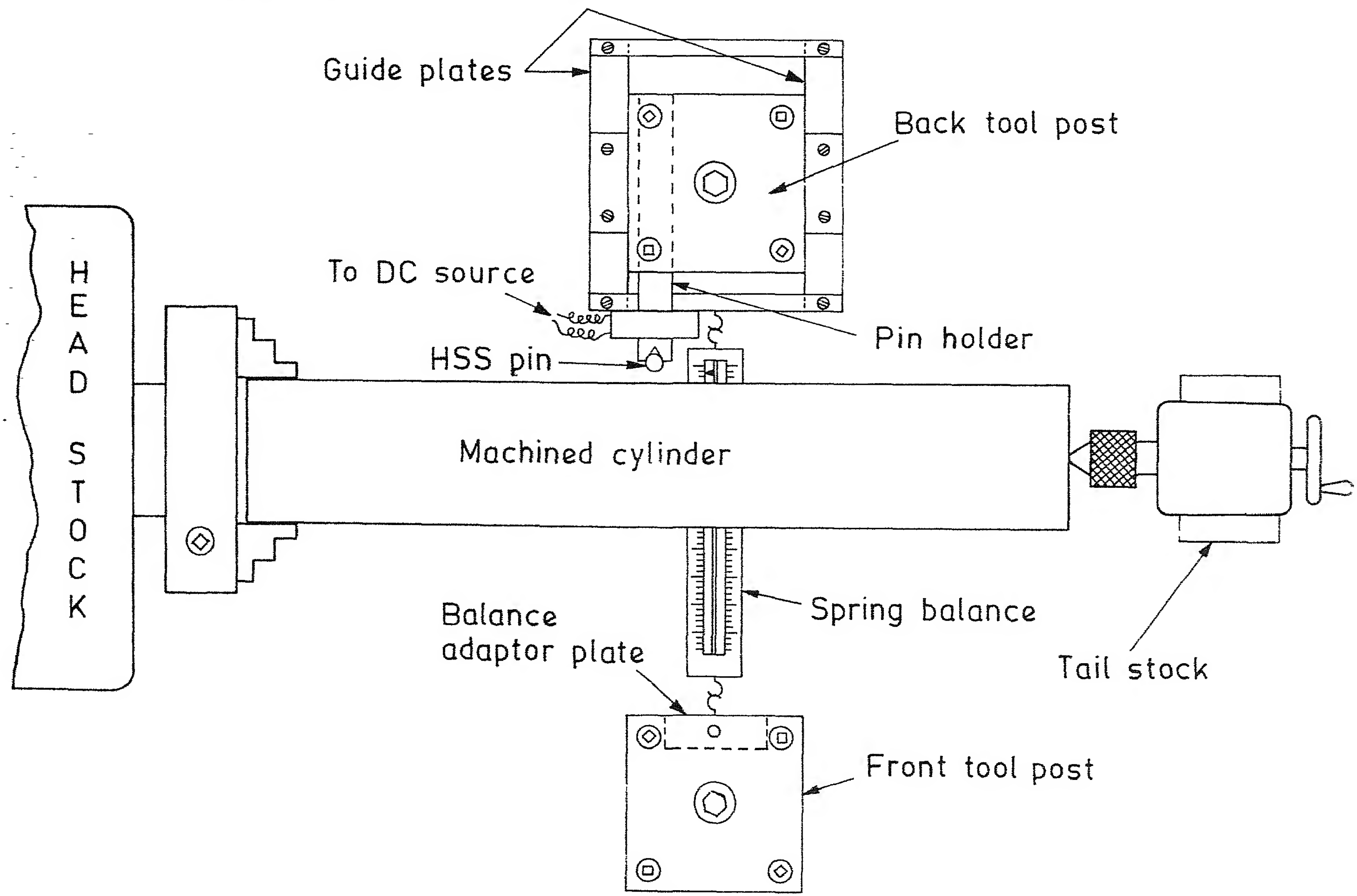


Fig. 3 SCHEMATIC VIEW OF WEAR-TEST RIG.

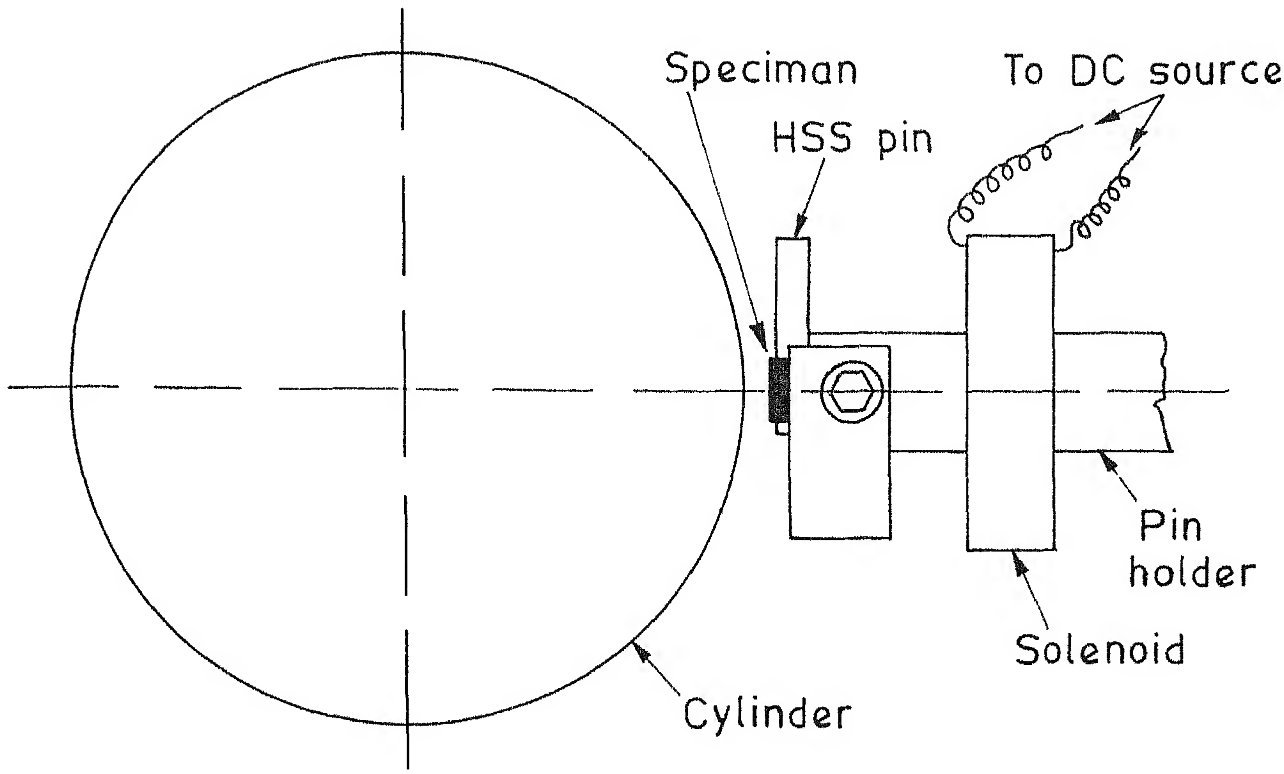


Fig. 4a. Close - up view : cylinder - speciman interface.

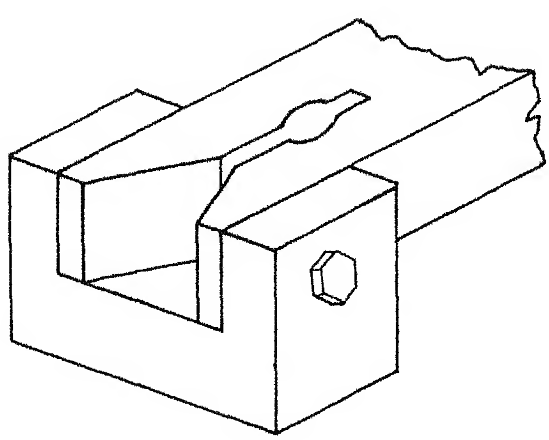


Fig. 4b. Pin holder and 'C' clamp.

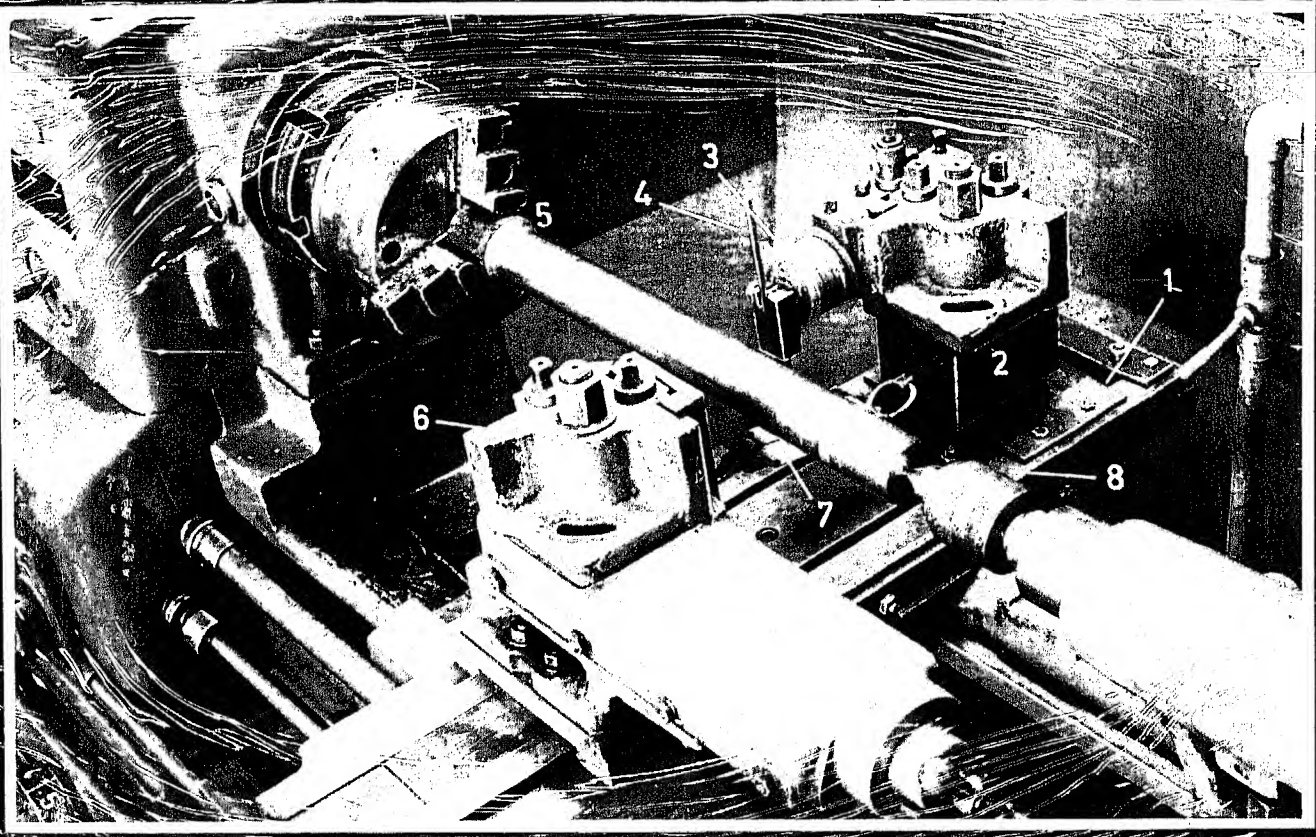
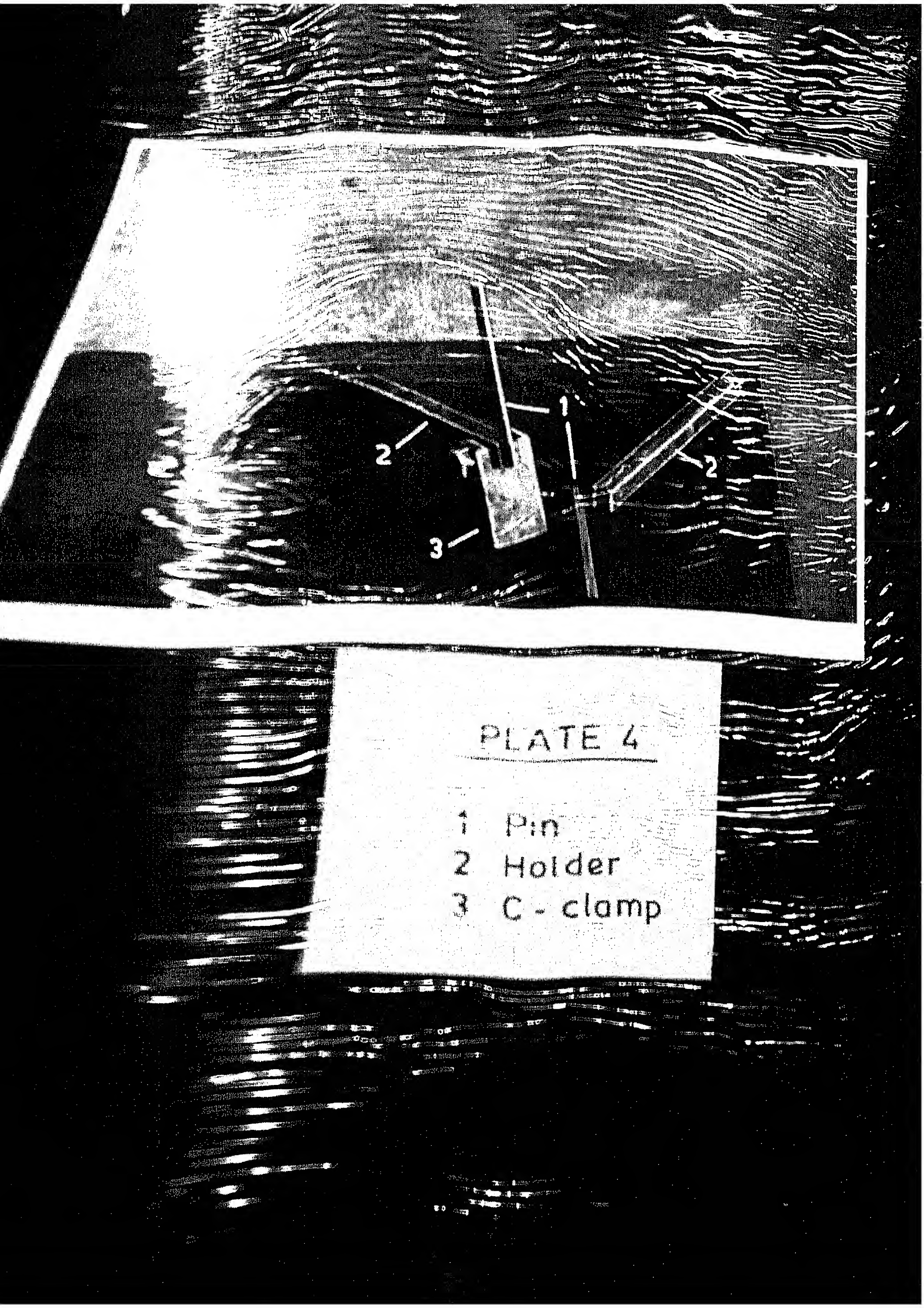


PLATE 3

1 Guide plate
2 Back tool post
3 Solenoid
4 H.S.S. pin
5 Chuck
6 Front tool post
7 Spring balance
8 Rolling centre


1
2
2
3
PLATE 4
1 Pin
2 Holder
3 C - clamp

filed to match the pin holder cross-section, served to excite the pin. The magnetising current was supplied through an external power pack.

Two identical pin-holders were used - one for the non-magnetic runs and the other for the magnetic experiments. (The solenoid was filed to suit the latter alone). The pin-holder, (Fig. 4b) had a VEE machined into the end face of a rectangular section (12.5 x 12.5 mm^2) of high carbon steel. A slit, 3 mm wide, 30mm long was machined central to the Vee, along the longitudinal axis of the holder. A 'C' clamp, operating normal to the slit axis, effected taut clamping of the ribbon of metglas wound around a H.S.S. pin supported on the base of the 'C' clamp (Plate 4a). Holes, drilled at suitable locations on the slit, enabled easy clamping. A schematic view is provided in (Fig. 3).

3.4.1 <u>The Modus Operandi</u>

The trailing end of the ribbon, tightly wrapped around the H.S.S. pin was inserted into the slit and pulled back such that the H.S.S. pin sat snugly against the Vee. The 'C' clamp was tightened, after ensuring the absence of play between ribbon and pin over the entire length of the ribbon. The holder was then clamped in a tool post, mounted on movable slide constrained to move normal to the lathe axis by slides and cross-members. (Fig. 3, Plate 3). This assembly

constituted the back-tool-post. The solenoid, when used was placed between the 'C' clamp and front face of tool post (Plate 3). The holders had markings etched into them to ensure identical overhang of ribbon. The spring balance, to indicate the magnitude of the load was placed in suitable locations between the front and back tool posts.

The cross-slide of the lathe was brought towards the operator till the ribbon contacted the cylinder and the load on the spring-balance reached the desired value. The cylinder, be it brass or mild steel, held between a three jaw and self-centering chuck and a rolling centre, was subjected to the following treatment before use.

1. Turned with a single point tool, from front tool-post.
2. Removed the tool and chatter marks through the prolonged use of a smooth-file with copious quantities of chalk.
3. Polished with 120 emery, oil and 400 grit lapping compound (Silicon carbide).
4. Polished with 180 emery oil and 400 grit lapping compound.
5. Polished with 240 emery, oil and 400 grit lapping compound.
6. Polished with 320 emery, oil and 400 grit lapping compound.

7. Finish polished with jute coir impregnated with 400 grit lapping compound and oil.

8. Surface cleaned with kerosene.

9. Degreased with acetone.

This sequence and this sequence alone yielded a surface finish of 0.6 - 0.8 microns rms on mild steel and 0.2 - 0.3 microns rms on brass. A Micro-metrical Profilometer was used to determine the surface finish. Ample time was allowed for the material to regain room temperature.

The ribbon was then brought to bear on the surface of the cylinder, as already described. The speed (checked with a tachometer) and feed were set at the desired value. The longitudinal feed dial was set to zero and the jibs tightened. (In the case of the magnetic experiments the coil was energised; the coil was positioned to give an identical orientation to the field). The machine was then started and switched off either after 30 mm, indicated on the dial, or after 1 min. indicated on a stop-watch. The ribbon was removed, indexed, the system demagnetised and experiment repeated. In every case the ribbon was cleaned with acetone prior to start.

The experiments were repeated:

1. A minimum of five times in the case of mild steel. With mild-steel a lot of problems cropped up; the ribbon would tear or the mild steel surface would get scoured. Both

problems appeared to be due to (a) Poor surface geometry of mild-steel surface, due to extensive hand polishing and consequent increase in load (b) Lack of homogenuity in the material (as one approaches the core the incidence of scouring increased).

2. Three times in experiments involving brass. The short length of the brass rod and large patches of porosity at one end were the reasons.

3. Three times in the case of the 1 min. runs.

The major axis of the elliptical wear-scar was measured at magnifications of 50 on the Carl Zeiss Jena MP 320 Shadowgraph.

The wear volumes were calculated using the equation,

$$\text{Wear volume} = \frac{1}{16}(d_o)^4 \sqrt{\frac{r_p}{(r_c)^3}} \qquad \text{[Ref. 11, App.1]}$$

where,

d_o = major axis of elliptical wear scar.

r_p = radius of H.S.S. pin.

r_c = radius of cylinder.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.0 Introduction

The results are given in three parts viz.

a) Stress-Relaxation,

b) Creep, and

c) Wear.

The discussion, in light of the theory outlined in Chapter II, follows the presentation of the results.

4.1 Results

4.1.1 Stress - Relaxation Test

There was a very nominal drop in the internal stress when the material was allowed to relax in a magnetic environment when compared to that in the non-magnetic test (Fig. 3). However, the reduction ($\Delta\sigma$) is not a true representation of the exact value. This is so because the drop in internal stress while being discernable was not accurately measurable. Repeated tests did confirm this slight decrease. In the loading path of the curve a difference in slope is indicated. This is due to difference in chart speeds used viz. - origin to kink 3 cm/min. - kink to full load 1 cm/min.

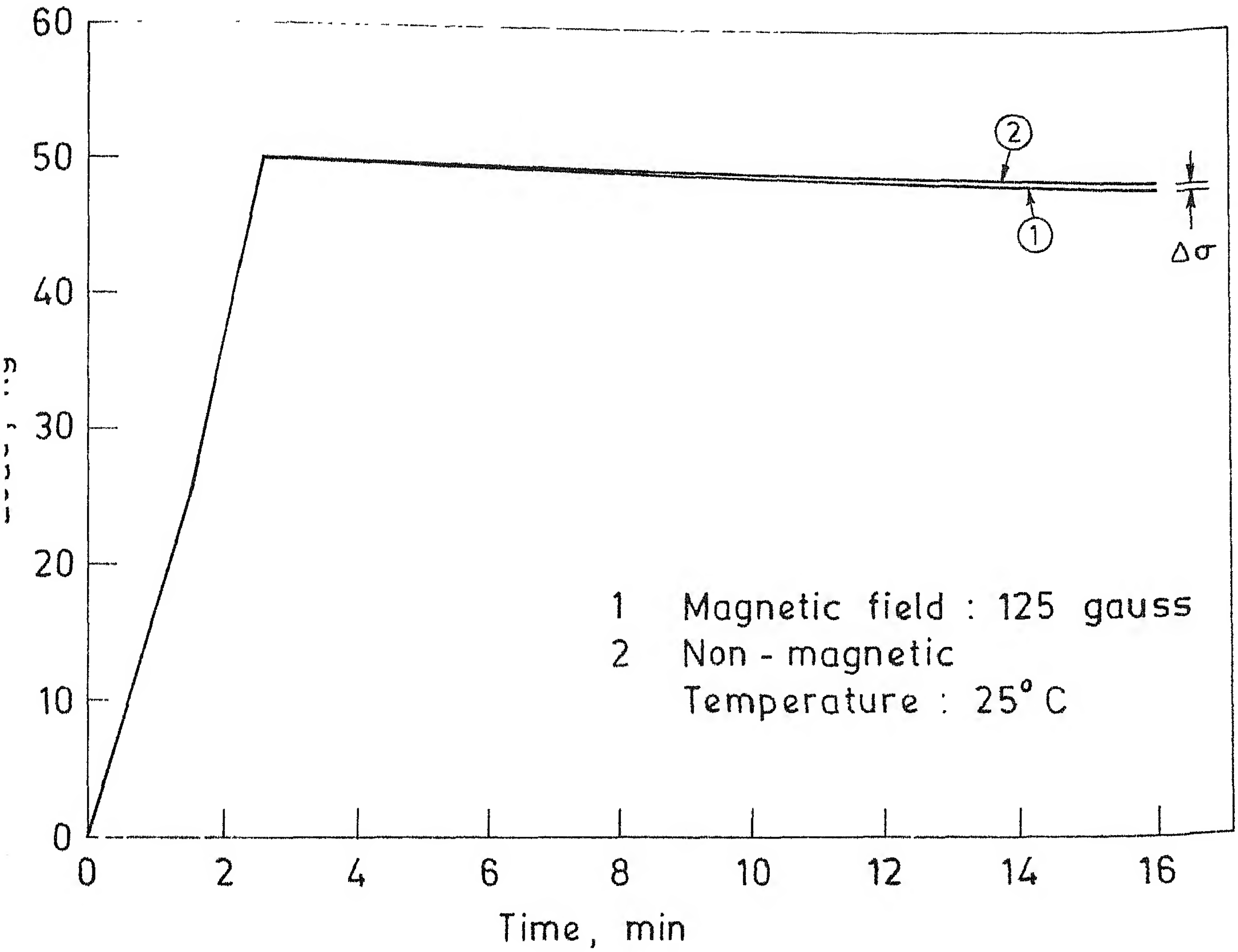


Fig. 5 Stress relaxation test on METGLAS® 2826 MB .

The theoretical estimate of the drop has not been calculated as the formulation and mechanisms are not very well understood.

4.1.2 The Creep Test

The results of this test are indicated in (Fig. 6). In a magnetic medium, the creep rate is enhanced; the maximum value of this increase is 88% over that, in the non-magnetic trials and the minimum is 32% .

The creep curves shown are the averaged plots. The increments in extension were not as smooth as is indicated; these increases were in finite steps. Once such an increment occurred, there was no further increase for a period of time ranging from a few minutes in the initial stages to a few hours in the later phases. The creep curve trend agrees well with those indicated by Gilman [1].

The LVDT was not calibrated and hence the extension is in graph units and not in a dimension of length.

4.1.3 Wear Test

The results of the wear tests are plotted in Figs. 7a, 7b, 8a and 8b. The values are tabulated below.

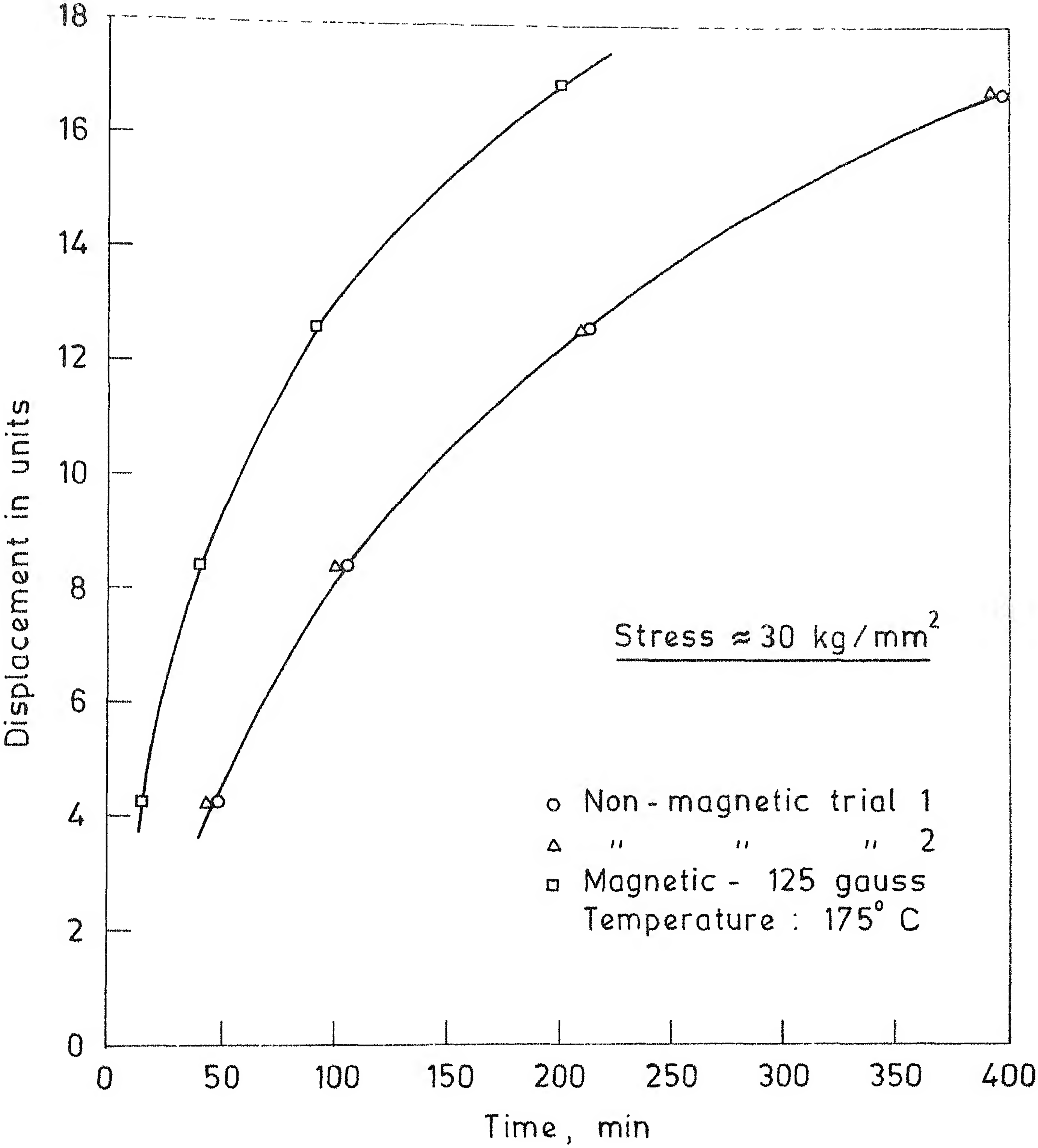


Fig. 6 Creep test on METGLAS® 2826 MB

4.1.3 (a) Against Brass

Length of rub = 30 mm

Radius of pin r_p = 3.17 mm

Load/Speed/Feed /cylinder Dia./Material
(Kg) (rpm)(mm/rev) $2r_c$ mm (Brass/M.S.)

5 / 100 / 0.1 / 53.2 / B

Trial No.	Non-Magnetic Pin		Magnetic Pin (60g)		Magnetic Pin(125 g)	
	d_o	W	d_o	W	d_o	W
1.	1.587	0.00515	1.697	0.00673	1.697	0.00673
2.	1.606	0.00540	1.669	0.00629	1.670	0.00631
3.	1.611	0.00546	1.601	0.00533	1.653	0.00605
	$W_{av.}$	0.00534		0.00612		0.00637

5 / 160 / 0.1 / 53 / B

Trial No.	Non-Magnetic Pin		Magnetic Pin (60g)		Magnetic Pin (125g)	
	d_o	W	d_o	W	d_o	W
1.	2.030	0.01385	2.058	0.01463	2.022	0.01364
2.	2.033	0.01393	1.966	0.01219	2.071	0.01561
3.	2.036	0.01402	2.023	0.01366	2.038	0.01407
	$W_{av.}$	0.01393		0.01349		0.01424

5/250 / 0.1 / 52.2 / B

Trial No.	Non - Magnetic Pin		Magnetic Pin (60g)		Magnetic Pin (125g)	
	d_o	W	d_o	W	d_o	W
1.	2.057	0.01494	1.919	0.01132	2.034	0.01428
2.	2.075	0.01547	2.189	0.01916	1.948	0.01202
3.	1.850	0.00978	2.024	0.01401	1.991	0.01311
	$W_{av.}$	0.01340		0.01483		0.01314

5/500 / 0.1 / 51.7 / B

Trial No.	Non-Magnetic Pin		Magnetic Pin (60g)		Magnetic Pin (125g)	
	d_o	W	d_o	W	d_o	W
1.	1.833	0.00956	1.780	0.00850	1.847	0.00985
2.	1.821	0.00931	1.782	0.00854	1.788	0.00865
3.	1.823	0.00935	1.809	0.00907	1.839	0.00968
	$W_{av.}$	0.00941		0.00870		0.00939

4.1.3(b) Against Mild Steel

Length of rub = 30 mm

Radius of pin r_p = 3.17 mm

Load / Speed / Feed / Cylinder Dia. / Material
(Kg) (rpm) (mm/rev) $2r_c$ mm (Brass/M.S.)

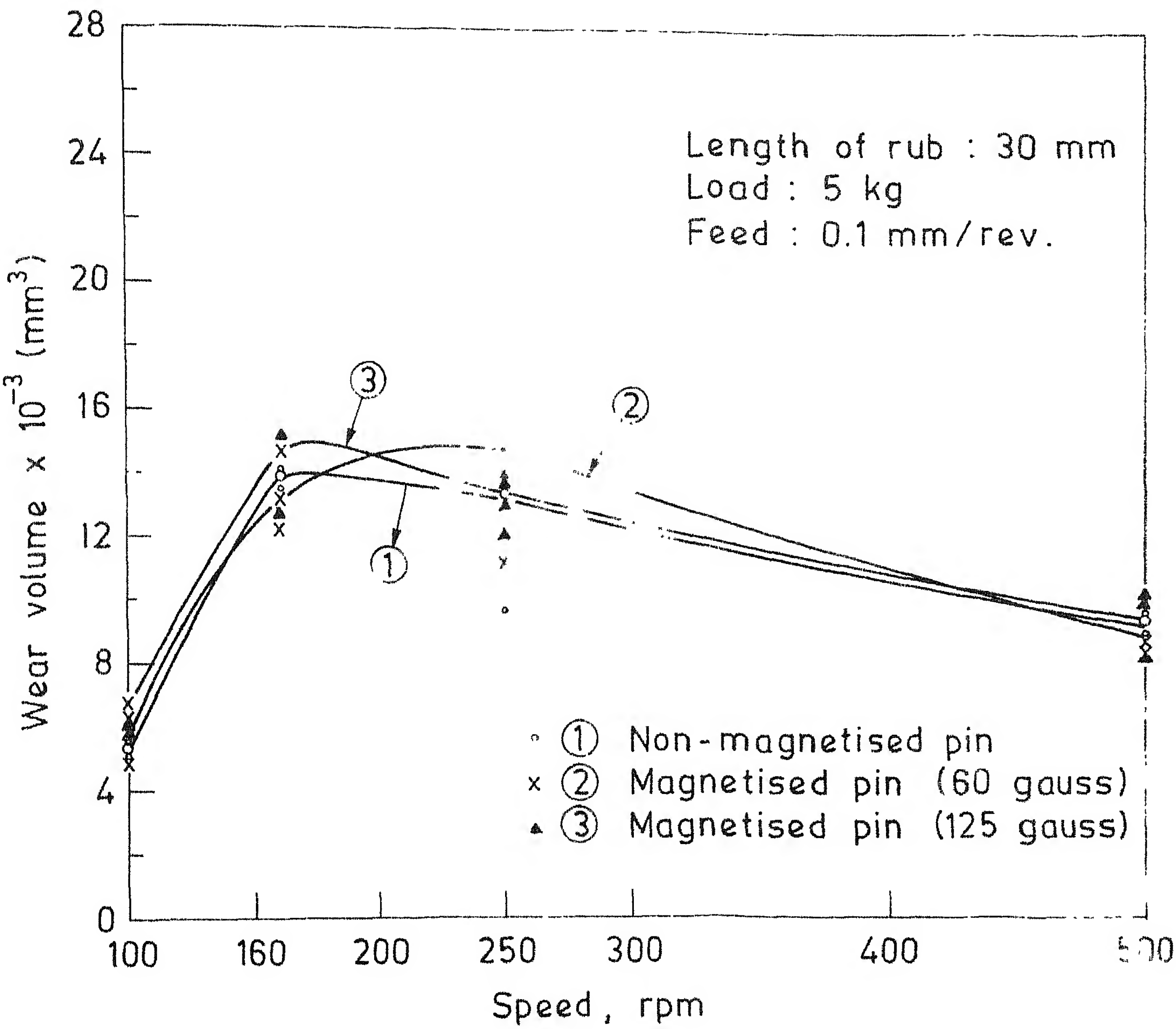


Fig. 7a Wear of METGLAS® 2826 MB (against brass).

5 / 100 / 0.1 / 56.2 / M.S.

Trial No.	Non - Magnetic pin		Magnetic Pin (125g)	
	d_o	W	d_o	W
1.	2.013	0.01370	1.594	0.00539
2.	2.118	0.01679	1.803	0.00882
3.	1.682	0.00668	1.994	0.01319
4.	1.875	0.01031	2.003	0.01343
5.	2.070	0.01532	1.975	0.01272
	$W_{av.}$	0.01256		0.01071

5 / 160 / 0.1 / 53 / M.S.

Trial No.	Non - Magnetic Pin		Magnetic Pin (125g)	
	d_o	W	d_o	W
1.	2.094	0.01568	2.138	0.01704
2.	2.069	0.01495	2.113	0.01626
3.	1.964	0.01214	2.113	0.01626
	$W_{av.}$	0.01426		0.01652

5 / 250 / 0.1 / 52.3 / M.S.

Trial No.	Non-Magnetic Pin		Magnetic Pin (125 g)	
	d_o	W	d_o	W
1.	1.986	0.01300	1.914	0.01117
2.	1.816	0.00905	1.800	0.00874
3.	1.991	0.01307	1.803	0.00879
4.	1.745	0.00702	2.007	0.01359
5.	1.774	0.00824	1.901	0.01088
	$W_{av.}$	0.01022		0.01062

5 / 500 / 0.1 / 52 / M.S.

Trial No.	Non-Magnetic Pin		Magnetic Pin (125g)	
	d_o	W	d_o	W
1.	1.635	0.00600	1.897	0.01087
2.	1.775	0.00833	1.967	0.01257
3.	1.780	0.00843*	1.682	0.00672
4.	1.814	0.00909	1.754	0.00794
5.	1.878	0.01044	1.796	0.00873
	$W_{av.}$	0.00846		0.00937

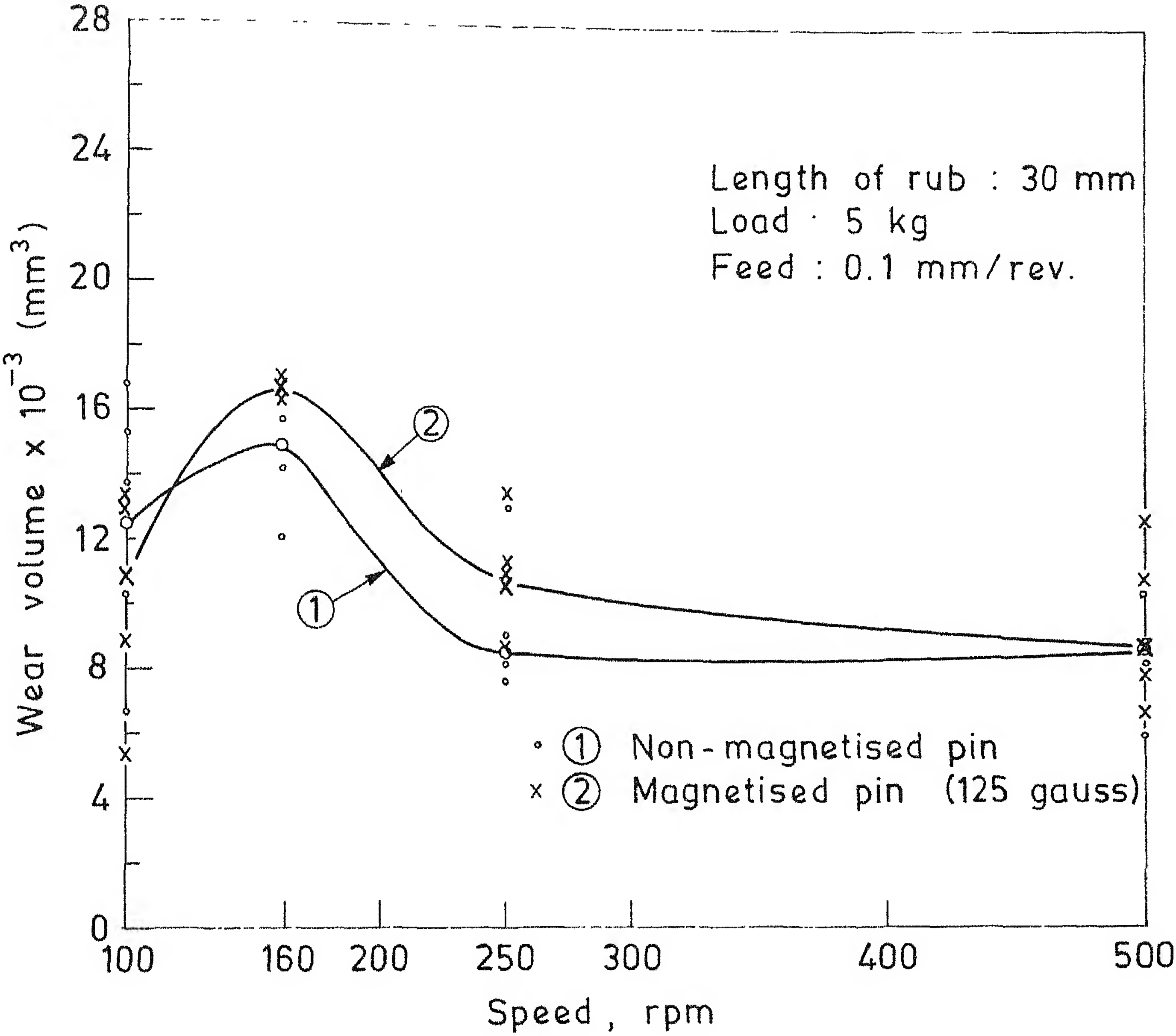


Fig. 7b Wear of METGLAS® 2826 MB (against mild steel).

4.1.3 (c) Against Brass

Time of rub = 1 min.

Radius of pin r_p = 3.17 mm

5 / 100 / 0.1 / 49.6 / B

Trial No.	Major Axis d_o	Wear Volume W
1.	2.308	0.02557
2.	2.018	0.01494
3.	2.130	0.01855
4.	2.240	0.02268
5.	1.995	0.01427
	$W_{av.}$	0.01920

5 / 160 / 0.1 / 49.6 / B

Trial No.	Major Axis d_o	Wear Volume W
1.	2.263	0.02363
2.	2.074	0.01667
3.	2.157	0.01750
	$W_{av.}$	0.01993

5/ 250 / 0.1 / 50.3 / B

Trial No.	Major Axis d_o	Wear Volume W
1.	2.108	0.01742
2.	2.146	0.01871
3.	2.161	0.01924
4.	2.368	0.02774
5.	2.009	0.01437
	$W_{av.}$	0.01950

5 / 500 / 0.1 / 51.1 / B

Trial No.	Major Axis d_o	Wear Volume W
1.	2.272	0.02296
2.	2.418	0.02945
3.	2.224	0.02108
	$W_{av.}$	0.02450

4.1.3 (d) Against Mild Steel

Time of rub = 1 min.

Radius of pin r_p = 3.17 mm

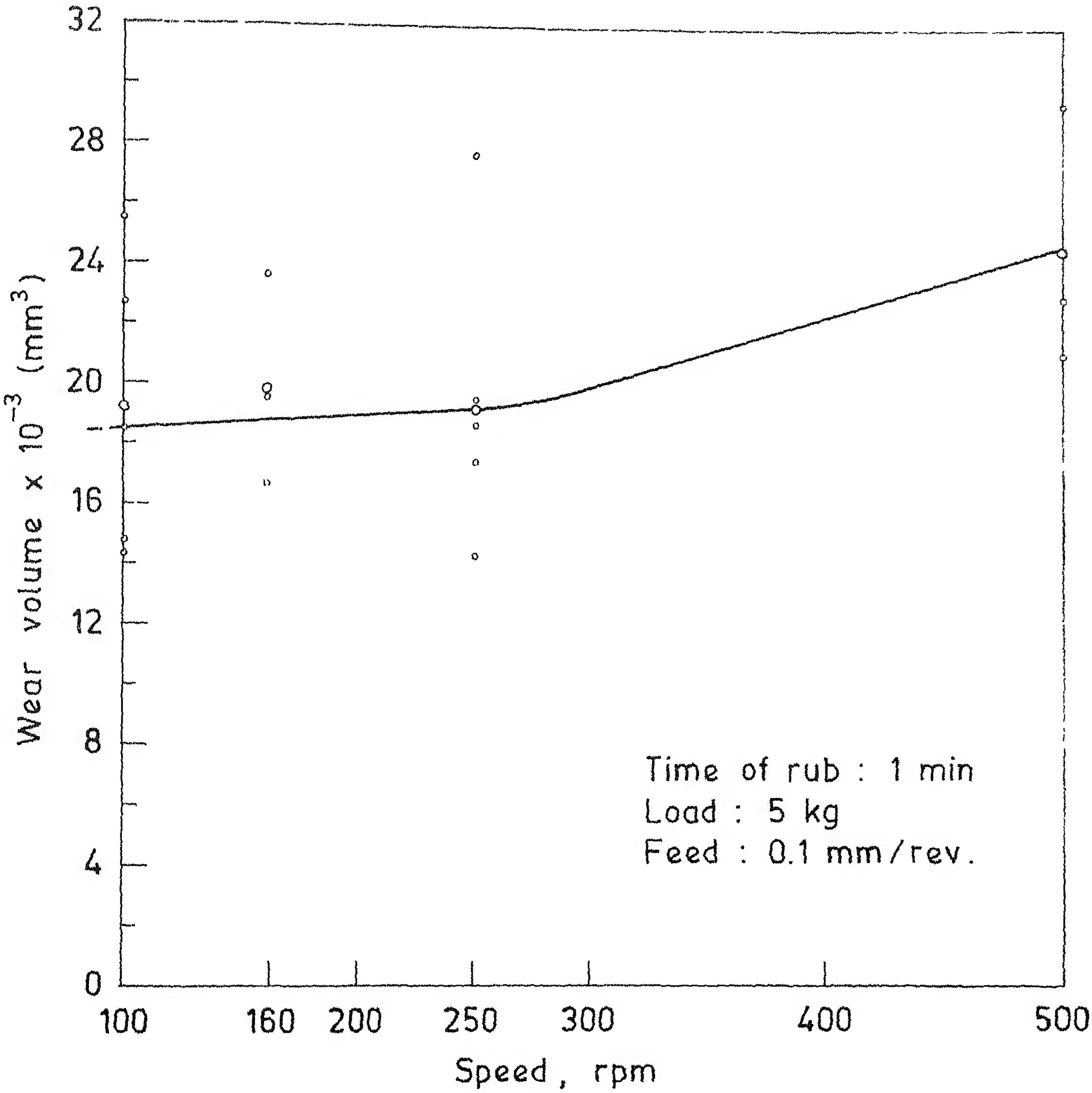


Fig. 8a Wear of METGLAS® 2826 MB (against brass).

5 / 100 / 0.1 / 49.8 / M.S.

Trial No.	Major Axis d_o	Wear Volume W
1.	1.486	0.00437
2.	1.545	0.00510
3.	1.645	0.00656
	$W_{av.}$	0.00656

5 / 160 / 0.1 / 49.8 / M.S.

Trial No.	Major Axis d_o	Wear Volume W
1.	1.573	0.00549
2.	1.585	0.00569
3.	1.820	0.09830
	$W_{av.}$	0.00693

5 / 250 / 0.1 / 50.3 / M.S.

Trial No.	Major Axis d_o	Wear Volume W
1.	1.742	0.00812
2.	1.729	0.00788
3.	1.743	0.00814
4.	1.679	0.00701
	$W_{av.}$	0.00779

5 / 500 / 0.1 / 50.3 / M.S.

Trial No.	Major Axis d_o	Wear Volume W
1.	2.331	0.02605
2.	2.331	0.02605
3.	2.302	0.02473
	$W_{av.}$	0.02561

d_o = Major Axis of elliptical wear scar in mm

W = Wear volume in $(mm)^3$

$W_{av.}$ = Average wear volume in $(mm)^3$

4.2 A Brief Discussion on the Wear Results

There appears to be a marginal increment in the wear volumes in both the case of brass and mild steel. However, in the case of brass this trend is not very explicit. The point to be noted is that these tests were very difficult to perform as the ribbon tore many times especially when rubbed against mild - steel. The scatter is indicated in the graphs. When rubbed against brass this scatters is less. This leads one to believe that there was some inexplicable effect in the case of mild-steel. Probably, mild steel being ferromagnetic, set-up a cross field or as mentioned earlier the surface waviness which is more pronounced in mild steel, gave rise to sudden

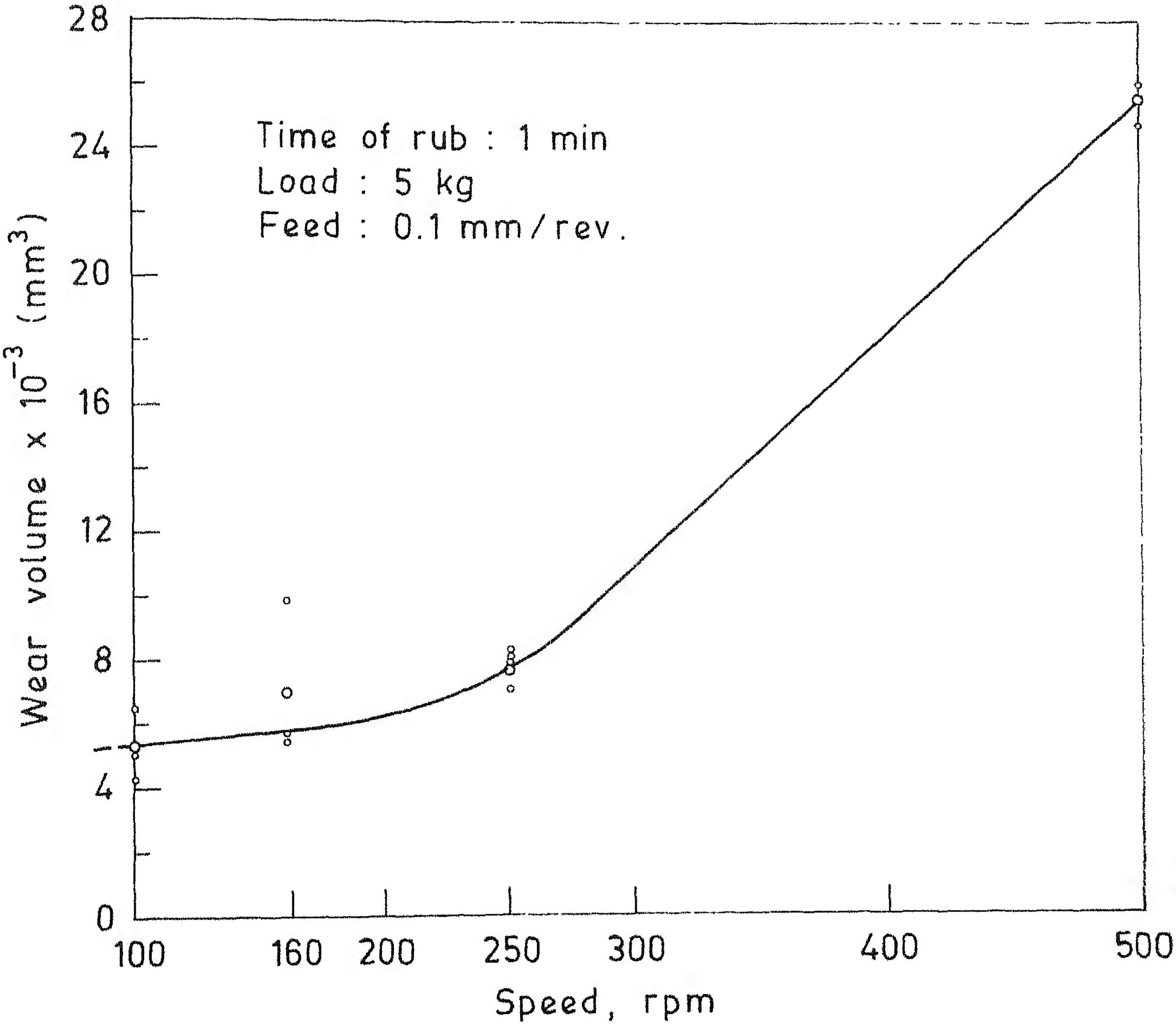


Fig. 8 b Wear of METGLAS® 2826 MB (against mild steel).

sharp load fluctuations resulting in tearing. (It was experimentally verified that a sudden increase in load led to tearing of the material).

The progress of growth of wear land is indicated in figures 8a and 8b. The trend in both cases is the same. Repeated experiments showed that this curve is not as linear as it should be. The test could not be duplicated in a magnetic field because of experimental problems.

4.3 Discussion

The drop in internal stress could possibly be explained on the basis of this simple calculation.

The drop in internal stress is proportional to λG_s

where λ is the magnetostrictive coefficient

G_s is the shear modulus

λ for Fe-Ni amorphous alloys $= 20 \times 10^{-6}$

G_s for Fe-Ni amorphous alloys $= 3.2 \times 10^{11}$ dynes/cm²

$= 3.3 \times 10^{5}$ Kgf/cm²

$\therefore$ Drop in Internal stress $= \lambda\ G_s$

$= 3.3 \times 10^{5} \times 20 \times 10^{-6}$

$= 6.6$ Kgf/cm²

The assumption made is that the drop in internal stress for amorphous material can be calculated along the same lines as that for crystalline materials. (In the latter, this

works out to be 50 Kgf/cm^2). This is quite in agreement with the flow mechanisms outlined. In a crystalline material once a dislocation starts moving the probability that it will stop earlier is less than that for amorphous materials which need the relaxation period for stability and volume conservation.

As can be seen the drop in internal stress for amorphous metals is of the order of 1/8-th that of crystaline metals. Curiously enough the creep rate also increases by roughly the same amount

[Crystalline materials = 500% average]

[Amorphous materials = 60% average]

The wear volumes are almost unchanged because of the fact that in amorphous materials, the particle size being so very small sets up a very large stress gradient, making migration of those free volumes more difficult than in the case of the coarser grained crystalline materials where the stress gradient is lower. Hence wear will be an intensely local phenomenon. The external stress is simply not propogated through the material.

CHAPTER V

CONCLUSIONS

5.0 Conclusions

The results of the investigation indicate that the deformation of amorphous metals, while being enhanced in an external magnetic field, cannot be attributed to 'dislocation mobility' - at least not in the usual sense this term implies. While dislocations in crystalline materials are the result of the kinetics of crystal growth and are permanent features in the crystal, they are a part and parcel of amorphous metals in so far as they are present in both the liquid and solid phases; also, they are transient phenomena in amorphous metals.

In the latter, the conditions under which these 'dislocations' or 'point defects' can move are more exacting than those in crystalline substances. However, the effect of an external magnetic field, qualitatively, on the mobility appears to be the same in both cases; quantitatively, the effect is less pronounced in amorphous metals. This can be explained on the basis of the flow mechanisms in the two cases being vastly different.

Classically, amorphous substances are considered to have no defects or dislocations. And hence, an external

magnetic field should in no way enhance properties like creep, wear etc. But in practice it does, although to a lesser extent. In amorphous materials these disconti-nuities, are not termed dislocations. The concept of 'free-volumes', which in a general sense resembles that of dislocations, explains the relatively marginal increase in the values of these properties in a magnetic environment.

5.1 Scope for Future Work

All in all the free-volume concept appears to yield satisfactory explanations. Herein lies scope for much future work.

A mathematical calculation of the drop in internal stress and the consequent explanation of the enhanced creep rate would be a very significant contribution. If the free volume concept is agreeable, the composition of the alloy can be altered to yield interesting data. Even in the areas attempted more data would enable a positive approach. To ensure this, however, the sensitivity of the instruments should be an order of magnitude higher than the ones used. The wear experiments should be attempted if and only if means to achieve satisfactory surface geo-metries consistently are available. Not much work along the lines attempted appear to have been done and hence forages in this direction look rather attractive and exciting.

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